

Lund 1977

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FOR BRIDGING VEIN DISRUPTION
CALCULATED WITH A MATHEMATICAL MODEL

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Lund, Sweden

1977



Summary

Based on an observed case of RC-injuries (rotational cerebral injuries with disruption of the parasagittal bridging veins and brain stem lesions), caused by a fall from a chair, a mathematical model for short head impact has been formulated. Possible magnitudes of head angular acceleration, $\ddot{\phi}$, and change in head angular velocity, $\Delta\dot{\phi}$, have been calculated. Compared with earlier proposed criteria for bridging vein disruption ($\ddot{\phi}_{\max} > 4500 \text{ rad/sec}^2$, $\Delta\dot{\phi} > 50 \text{ rad/sec}$) the present results indicate that the earlier proposed velocity criterion should be reduced to $\Delta\dot{\phi} > 30 \text{ rad/sec}$.

Introduction

Disruption of parasagittal bridging veins - i.e. superior cerebral veins crossing the subdural space from the upper surface of the brain to the superior sagittal sinus - is a common lesion when the head is subjected to angular motion caused by blunt trauma against the face or the back of the head. Skull fracture is often absent. Disruption of many or all bridging veins is as a rule accompanied by brain stem lesions and occasionally by subcortical hemorrhages close to the superior margin of the head (Voigt and Saldeen, 1968). Mostly these kinds of injuries occur in traffic accidents but can be seen as well in persons, who have fallen to the ground from an upright position (Voigt, Löwenhielm and Ljung, 1977). In the latter cases the head angular acceleration certainly exceeds the critical value if the impacted surface is rather stiff. Then, the change in angular velocity becomes decisive. But, since the impact velocity can sometimes be fairly well estimated a possibility arises to calculate this change. Thereby fairly accurate estimates of the velocity part of the criterion for disruption of the bridging veins can be acquired.

In a recently observed case, disruption of bridging veins occurred as the result of a fall from a chair. Based on this case possible head angular accelerations and velocities have been studied by means of a mathematical model which takes the yielding properties of the impacted surface into account. The model also allows some conclusions to be drawn about other experiences of bridging vein disruption due to fall to the ground.

Case Report

In a care clinic for handicapped children a retarded girl (10 years old, 0.85 m tall) was found unconscious prostrate on the carpeted floor in front of a plastic armchair in which she had been sitting. During transport to hospital the girl was given oxygen and external heart massage. On admission she was intubated, but no voluntary respiration could be restored and the treatment was discontinued.

Autopsy revealed the following injuries: On the chin were skin abrasions (cf. fig. 1a) and around the mandibular articulations hemorrhages caused by the impact of the chin against the floor. Several bruises on the breast were probably caused by the external heart massage. There were minor bruises on the left arm, the right shoulder, the back and on the knees. The skull was intact. Numerous bridging veins were disrupted (cf. fig. 1b), with a moderate subdural hematoma. The brain showed swelling with bilateral tentorial impression on the parahippocampal gyri with surrounding cortical hemorrhages. As sign of brain stem injury perivascular hemorrhages could microscopically be seen in the mesencephalon. The cerebral injuries were the cause of death.

The Mathematical Model

The mathematical model chosen is shown in fig. 2. The head is regarded as a homogeneous sphere with mass m , radius R and principal moment of inertia $J = \frac{2}{5}mR^2$. By action of the forces $H(t)$ and $V(t)$ the point P is moved a distance $v_0(t)$ in the vertical direction. $v_0(t)$ corresponds to the yielding capabilities of the hit surface and the soft tissues of the head. The reason that P is restricted to move in a vertical direction is the assumption of full friction between the contact surfaces and that the impact velocity is achieved by gravity alone. $v(t)$ and $u(t)$ denote vertical and horizontal displacements of the sphere center.

$$\ddot{\phi}(t) = \frac{\sin\phi \cdot \ddot{v}_0(t)}{R \cdot (1 + \frac{J}{mR^2})} \quad (6)$$

Suppose now that the impact velocity is w and the maximum indentation at the contact surfaces is s_0 . $\ddot{v}_0(t)$ is supposed to be constant during impact and can therefore be written as:

$$\ddot{v}_0(t) = \begin{cases} \frac{w^2}{2s_0} & 0 < t \leq t_1 \\ 0 & t > t_1 \end{cases}$$

where $t_1 = 2s_0/w$ is the duration of the impact.

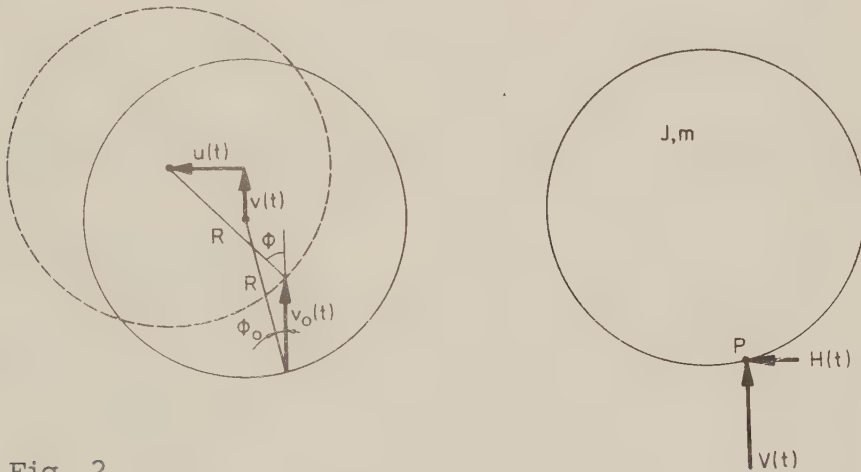


Fig. 2.

Mathematical model for head motion during impact on a yielding surface.

Hence, from (6):

$$\ddot{\phi}(t) = \frac{\sin\phi \cdot w^2}{2s_0 \cdot R (1 + \frac{J}{mR^2})} \quad (7)$$

Since the displacements of the head are estimated to be much smaller than R during impact, the influence of the neck can be neglected. This is the reason the head is studied isolated.

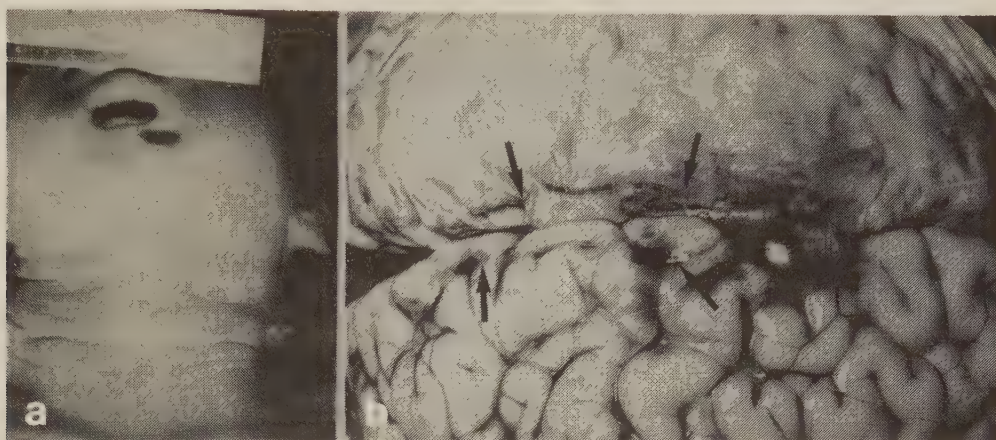


Fig. 1

Autopsy findings. a) skin abrasions on the chin. b) disruption of bridging veins.

Calculation and Discussion

From fig. 2 the following geometrical conditions can be obtained:

$$R \cdot \cos\phi_0 + v(t) = R\cos\phi + v_0(t) \quad (1)$$

$$R \cdot \sin\phi_0 + u(t) = R\sin\phi \quad (2)$$

The equations of motion are

$$J\ddot{\phi}(t) = V(t) \cdot R \cdot \sin\phi + H(t) \cdot R \cdot \cos\phi = 0 \quad (3)$$

$$m\dot{v}(t) = V(t) \quad (4)$$

$$m\dot{u}(t) = H(t) \quad (5)$$

Differentiation of (1) and (2) gives together with (3), (4) and (5) an expression for the angular acceleration of the sphere:

By writing

$$\ddot{\phi}(t) = \frac{1}{2} \frac{d}{d\phi} (\dot{\phi})^2 \quad (8)$$

eq. (7) takes the directly integrable form:

$$d(\dot{\phi})^2 = \frac{\sin\phi w^2}{s_0 \cdot R \cdot (1 + \frac{J}{2mR^2})} d\phi \quad (9)$$

With the initial conditions

$$\left. \begin{array}{l} \phi = \phi_0 \\ \dot{\phi} = 0 \end{array} \right\} \text{ for } t=0$$

the integration yields

$$\dot{\phi}(t) = \sqrt{\frac{w^2 \cdot (\cos\phi_0 - \cos\phi)}{s_0 \cdot R \cdot (1 + \frac{J}{2mR^2})}} \quad \text{for } 0 < t \leq t_1 \quad (10)$$

which equation in turn is integrated to

$$\int_{\phi_0}^{\phi} \frac{d\phi}{\sqrt{\cos\phi_0 - \cos\phi}} = \frac{w \cdot t}{\sqrt{s_0 \cdot R \cdot (1 + \frac{J}{2mR^2})}} \quad \text{for } 0 < t \leq t_1 \quad (11)$$

For $t > t_1$ one obtains $\ddot{\phi}=0$, since no external force is acting.

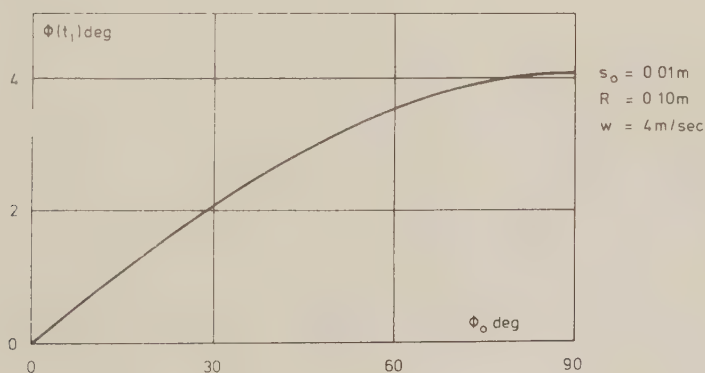


Fig. 3

$\phi=f(\phi)$ according to eq. (11).

Is it then possible that these tolerance levels for bridging vein disruption have been exceeded in the referred case? Because of her handicap, the girl was incapable of climbing the chair and it can be supposed that she fell forward off the chair from a sitting position and that the chin hit the carpeted floor. The height of the chair (0.4 m) together with the length of the torso (0.4 m) gives a fall of 0.8 m. The abrasions on the lower aspect of the chin suggest that the head had been struck in a tangential direction so that eqs. (14) and (15) can be applied to calculate the angular acceleration and velocity.

TABLE 1

$R\Delta\dot{\phi}$ and $R^2\ddot{\phi}$ at falls from two different heights.

$h(m)$	$w(m/s)$	$R\cdot\Delta\dot{\phi} (m/sec)$	$R^2\cdot\ddot{\phi} (m^2/sec^2)$
0.8	4.0	2.9	51
2.5	7.0	5.0	130

The head of a 10-year old child is still growing. The circumference of the head at this age is about 0.53 m and the radius of the skull curvature in the sagittal plane about 0.09 m. The yielding capacity of the chin - floor system (s_0) is assumed not to exceed 0.01 m. With these data, $R\Delta\dot{\phi}$ and $R^2\ddot{\phi}$ obtain the values given in Table 1.

As previously mentioned, changes of the skull radius R and of the indentation s_0 do not affect the $R\Delta\dot{\phi}$ -value, which is only dependent on the impact velocity. The influence of the $R^2\ddot{\phi}$ -value is directly proportional to R and to the inverse of s_0 (cf. eq. (14)), which is why the $R^2\ddot{\phi}$ -value is fairly insensitive to small changes of R and s_0 . Thus, the result given in Table 1 can be regarded as representative of the real life situation.

From Table 1 and fig. 4b it is appearant that the acceleration treshold is exceeded while the velocity change is well below the previously suggested critical level.

In view of the preceding discussion the conclusion emerges that the previously suggested tolerance level of $R \cdot \dot{\Delta\phi}$ is too high. The case studied suggests rather a tolerance level below $R \cdot \dot{\Delta\phi} = 2.9$ m/sec. The $\dot{\Delta\phi}$ level for human adults

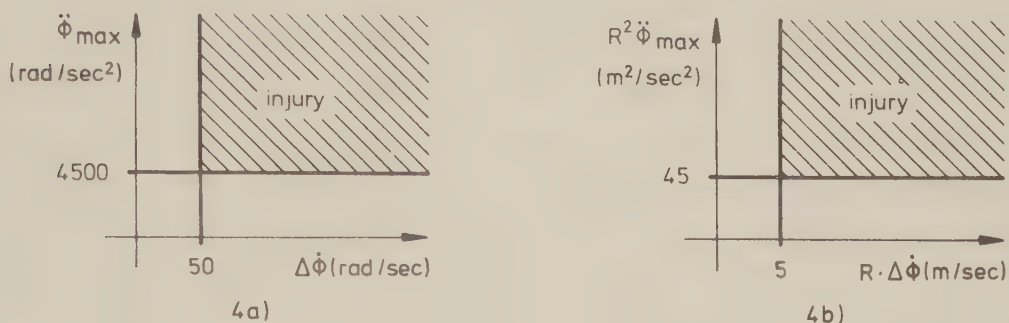


Fig. 4

Tolerance levels for bridging vein disruption.

proposed by Löwenhielm (1974b), which corresponds to $R \cdot \dot{\Delta\phi} = 5$ m/sec., was based on animal experiments. Factors such as scaling and differences in the geometrical shape of the skull-brain system of man and animal imply substantial uncertainties when data from animal experiments are to be transferred to man. Furthermore, knowledge of the biological scatter around an average tolerance level is lacking.

The duration of the impact in the case studied is very short ($t_1 = 5$ msec). However, disruption of the parasagittal bridging veins does not necessarily occur during impact. According to Löwenhielm (1975), maximal shear stresses in the brain matter occur about 7 msec after the impact if the impact duration is about 5 msec. It is reasonable to assume that bridging vein disruption coincides with the occurrence of these large shear stresses. Therefore, the displacement of the head may be substantial when disruption takes place and, consequently, the neglect of influence of the neck in the model might be questioned. The peripheral velocity after impact in the case studied is 2.9 m/sec., which gives an additional angular displacement of about 13 deg. It is believed that the influence of the neck during an angular movement of this magnitude could not considerably reduce the angular velocity of the head. In any case, the influence of the neck acts in the direction as to lowering the strain of the bridging veins.

Indeed, the present result is based on a separate case, and the incidence of bridging vein disruption is somewhat higher for the child than for the adult (Voigt and Löwenhielm, 1974). However, disruption of the parasagittal bridging veins is also occasionally seen in persons, who from a standing position have fallen to the ground; - the typical situation is the alcoholic who in an intoxicated state falls and strikes his head. These cases are difficult to reconstruct. In any case, such falls are well below 2.5 m, a fact which to some extent confirms the conclusion that the previously suggested tolerance levels are too high (cf. Table 1). Furthermore, the extreme conditions applied to the model (essentially about the unfavourable direction of impact), have probably not been at hand in all such cases. Thus a reduction of the tolerance criterion for $R \cdot \Delta \dot{\phi}$ at least to about 3 m/sec. seems to be called for.

The model shows that $R \cdot \Delta \dot{\phi}$ is independent of the softness of other than very soft hit surfaces (eq. (15)). On the other hand $R^2 \cdot \ddot{\phi}$ is strongly dependent on the softness of the hit surface, (eq. (14)), but it is noteworthy that a fall from only 0.8 m does not result in a tolerable angular acceleration of the head even if the indentation of the hit surface is assumed to be as much as 0.01 m. Thus a moderate fall may give rise to disruption of the parasagittal bridging veins, no matter whether the head strikes a concrete floor or a soft carpet. This fact has great practical forensic implications, for example, in the judgement of suspected battered child cases.

References

1. P. Löwenhielm, Z. Rechtsmedizin 75, 131-144 (1974)
2. P. Löwenhielm, J. Biomechanics 8, 351-356 (1975)
3. F. Unterharnscheidt and L.S. Higgins, Tex. Rep. Biol. Med. 27, 127-160 (1969)
4. G.E. Voigt and W. Lange, Proc. 15th Stapp Car Crash Conference, pp. 466-488, Society of Automotive Engineers, New York (1971)
5. G.E. Voigt and P. Löwenhielm, Hefte Unfallheilk. 117, 329-335 (1974)
6. G.E. Voigt, P. Löwenhielm and C.B.A. Ljung, Acta Neuropath. 39, 201-209 (1977)
7. G.E. Voigt and T. Saldeen, Dtsch. Z. ges. gerichtl. Med. 64, 9-20 (1968)

